LONDON-WEST MIDLANDS ENVIRONMENTAL STATEMENT

Volume 5 | Technical Appendices

CFA18 | Stoneleigh, Kenilworth and Burton Green

Stoneleigh, Kenilworth and Burton Green river modelling report (WR-004-011)

Water resources

November 2013

VOL 5

ES 3.5.2.18.15

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Appendix WR-004-011

Environmental topic:	Water resources and flood risk assessment	WR
Appendix name:	River modelling report	004
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1 Overarching modelling approach

1.1 Introduction

1.1.1 This section of the Proposed Scheme crosses numerous watercourses with the potential to affect flood risk. Hydraulic modelling has been carried out to assess the current (baseline) river flood risks at each of these watercourse crossings and the potential impacts of proposed culvert and viaduct structures. Therefore, the primary objective of this assessment is to assess the impact of the Proposed Scheme on river flood risk.

1.1.2 The outcome of this assessment has aided the design to determine the type and dimension of structures required to convey the watercourse flows; and mitigation measures for any remaining residual flood risk.

1.1.3 A hydraulic modelling assessment of flood risk was undertaken for watercourses affected by this section of the Proposed Scheme. These watercourses were grouped into seven Community Forum Areas (CFA) in this section. Existing hydraulic models of the watercourses have been utilised where available and new river hydraulic models were built for the other watercourses. This report describes the hydraulic modelling processes and outcomes of this assessment.

1.1.4 The main conclusions from this modelling annex form the basis of the river flood risk in the flood risk assessment (FRA) for CFA18 (WR-003-018). These conclusions are also reported within the Water Resources and Flood Risk Assessment section of Volume 2 of the Environmental Statement (ES).

1.2 Hydrology

1.2.1 Watercourses with existing hydraulic models adopted standard Flood Estimation Handbook (FEH) techniques for hydrological assessment. The hydrology of these models was reviewed for suitability for use in this study.

1.2.2 For the watercourses with no existing hydraulic models, hydrological assessments were undertaken in this study to determine the design flows.

1.2.3 The hydrological catchments of the watercourses to each of the route crossings have been determined from the FEH CD-ROM[1] for watercourses represented in this data set. For the purposes of this assessment it was assumed that catchment boundaries as represented in the FEH CD-ROM were correct, therefore a detailed assessment of catchment boundaries has not been completed. The catchment descriptors have also been taken from the FEH CD-ROM and updated for urban expansion to 2012, using Equation 6.8 in Volume 5 of the FEH[2]. This is a standard industry technique.

1.2.4 River flows at watercourse crossing locations were determined using the Revitalised Flood Hydrograph (ReFH) method[3] in the first instance. In line with the current Environment Agency flood estimation guidance[4], the ReFH method is deemed acceptable for the majority of catchments along the route and is the most time

[1] Centre for Ecology and Hydrology (2009) *FEH CD-ROM Version 3*, ©NERC (CEH).
[2] Centre for Ecology & Hydrology (CEH) (1999) *Flood Estimation Handbook – Volume 5: Catchment Descriptors.*
[3] Centre for Ecology & Hydrology (CEH) (2007) *The revitalised FSR/FEH rainfall-runoff method: Supplementary Report No. 1.*

efficient method for determining flows for studies where numerous flows are required.

1.2.5 The ReFH method is not considered acceptable for all catchments, in this case those classed as highly permeable. Based on the FEH CD-ROM catchment descriptors, a number of the catchments are classed as highly permeable and hence in line with current Environment Agency guidelines[4], an alternative method was required. Therefore, at these locations the FEH Statistical method, with a permeable adjustment was utilised, as recommended in the guidelines.

1.2.6 Not all watercourses that will be crossed by the route were represented in the FEH CD-ROM; therefore, the catchment boundaries could not be determined using the FEH CD-ROM. In these instances, catchment boundaries have been determined through the use of topographic data from Light Detection and Ranging (LiDAR) data and Ordnance Survey (OS) mapping at a 1:10,000 scale. At locations of uncertainty, a slightly larger catchment has been assumed as a conservative approach. Flows for these catchments were determined through a conservative area scaling method. Based on the flows estimated for FEH CD-ROM represented catchments, a maximum flow rate of 1.4 and 2.6m^3/s per km^2 was calculated for the 1 in 100 (1%) annual probability and 1 in 1000 (0.1%) annual probability events respectively. These flows rates, along with a 10% error allowance (to prevent an underestimation of flow), were used as scaling factors.

1.2.7 The estimated peak flows were used as either a constant inflow boundary or as a full hydrograph. The peak flows estimated using this method were for the 1 in 5 (20%) annual probability, 1 in 100 (1%) annual probability and 1 in 1000 (0.1%) annual probability events. Flow during the 1 in 100 (1%) annual probability event with an allowance for climate change was estimated by factoring the 1 in 100 (1%) annual probability flow by 20% (refer to 'Section 3 – Design Criteria' of the Flood Risk Assessment WR-003-018).

1.3 Hydraulics

General approach

1.3.1 The hydraulic modelling approach depended on the characteristics of the particular watercourse and floodplain hydraulics. The approach of either steady or unsteady modelling was based on whether there were rapid increases or decreases in flows, flood storage areas or structure impacts on channel/floodplain flows. The modelling approach also varied based on requirements of assessing the flow routes either in one dimension or two-dimensions.

1.3.2 The modelling approach adopted in this study was as follows:

- if the modelling was utilised for sizing the culvert crossings on watercourses with no significant floodplain attenuation or structure impacts, steady state one dimensional modelling was adopted;
- if there was significant floodplain attenuation and/or structure impacts on channel/floodplain flows, one dimensional hydrodynamic modelling was

[4] Environment Agency. 2012. *Flood estimation guidelines (197_08).*

adopted; and

- if there was significant floodplain attenuation and/or structure impacts on channel/floodplain flows, and a requirement for accurately defining the flood extents, two dimensional or a one dimensional -two dimensional combination modelling was adopted.

1.3.3 Existing models were first reviewed to assess their suitability for use. If more recent data such as topography was available the models were updated accordingly. If the level of detail within the model, such as the floodplain, was not appropriate, the model was upgraded accordingly.

1.3.4 The hydraulic modelling approach was based on the Environment Agency guidelines[5].

1.3.5 Two industry standard modelling packages have been utilised as part of this assessment: ISIS (version 3.6) and TUFLOW (version 2012).

Hierarchical approach

1.3.6 Any existing Environment Agency models for the watercourses were used to assess the current and future flood risk impacts of any watercourses crossing the route.

1.3.7 For watercourses without existing hydraulic models, the modelling process was carried out in a phased manner to assess the baseline flood risk and impacts of the Proposed Scheme. In the first phase, the watercourses with culverted crossings were modelled as simple unsteady one dimensional hydraulic models, to assess the adequacy of culverts in conveying flood flows. In the second phase, watercourses for both culverted and viaduct crossings were modelled as two dimensional hydrodynamic models to define the flood extents and assess the impacts of the various structures on flood risk. The two dimensional model outputs were then used to inform the design team of flood risk.

1.3.8 All the models were run for the 1 in 100 (1%) annual probability with an allowance for climate change and 1 in 1000 (0.1%) annual probability events. Some of the models were run for the 1 in 20 (5%) annual probability where the potential impacts on flood risk could affect vulnerable receptors.

1.3.9 The 1 in 100 (1%) annual probability with an allowance for climate change peak water levels for the baseline and Proposed Scheme were compared upstream and downstream of the crossing to assess the impact on flood risk. The scheme impact on flood risk and the width of the 1 in 100 (1%) annual probability with an allowance for climate change flood extents, defined the type of structure to be used at the crossings i.e. culvert or viaduct and the dimensions of culverts/viaducts. The structure type was selected based on its adequacy in conveying flood flows without significantly affecting flood risk.

1.3.10 The peak water levels for the 1 in 1000 (0.1%) annual probability event confirmed whether the vertical alignment met the design criteria (refer to 'Section 3 – Design Criteria' of the Flood Risk Assessment WR-003-018).

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[5] Environment Agency (2009) '*Requirements for completing computer river modelling for flood risk assessments – Guidance for developers*' Version 3.0.

Input data

1.3.11 The topographic data used was LiDAR data that was flown in 2012, covering the extent of the Proposed Scheme, providing data as fine as up to 0.2m horizontal resolution. This data was used to create digital terrain models (DTM) for use within the hydraulic models. In most cases, the DTM has been resized to a 1m resolution for suitability in the two dimensional models. For watercourses without existing hydraulic models, there were no topographic surveys available and hence river sections and floodplain topography were derived from these DTM.

1.3.12 For existing models, the floodplain topography was updated with this new DTM. The channel topography in these models was taken from topographic surveys undertaken previously.

1.3.13 Inflows to the watercourses were taken from the hydrological assessments as discussed in Section 0 of this report.

1.3.14 The data for the Proposed Scheme model scenario was taken from the scheme drawings.

One dimension modelling

1.3.15 In the first phase, one dimensional ISIS models were constructed representing a 200m to 300m reach of the watercourse. The purpose of these models was to assess the adequacy of culverted crossings in conveying flows. These models used the LiDAR data to define extended cross-sections which included the channel and floodplain topography. The roughness of the channels and floodplains is defined by the Manning’s roughness values parameter. The Manning's values were based on the particular land use type as observed from aerial photographs. Steady state flows were applied as upstream inflow boundaries and a normal depth boundary was applied at the downstream extent. The normal depth boundary was based on the bed slope of the topography at that location and is considered suitable for the purpose of the modelling.

1.3.16 The Proposed Scheme model included rectangular conduit units to represent the structures at the crossings. There were two types of culverts adopted: a minimum culvert size of 2m by 1.5m and a maximum culvert size of 4m by 2m. The dimensions adopted here represent the flow area of the culvert rather than the full dimensions of the culvert that would need to be larger to accommodate depressed inverts and mammal ledges as appropriate. The lengths of the culvert were based on the width of the route crossings as defined in the design.

Two dimension modelling

1.3.17 In the second phase, unsteady state two dimensional TUFLOW models were built to accurately define the flood extents and floodplain attenuation. The two dimensional models were built on a 5m cell resolution with LiDAR data used to create the DTM, which defined the floodplain and channel topography.

1.3.18 It should be noted that components within a two dimensional TUFLOW model such as SXZ, HX, Z-polygon, Z-Shape polygons, etc., are based on naming conventions as defined in the TUFLOW manual[6].

1.3.19 The Manning's roughness values of the channels and floodplains were based on the particular land use type as observed from aerial photographs.

1.3.20 The inflow to each watercourse was applied upstream using a TUFLOW boundary condition polyline layer, linking it to a flow time series within a boundary condition database. The flow type is either constant flow or hydrograph flow, depending on the attenuation within the floodplain. A flow-head (HQ) polyline layer was used for the downstream boundary, based on the slope of the floodplain at that location; which was considered suitable for the scale and level of detail of the modelling. The models have been run at a two second timestep for varying durations.

1.3.21 The Proposed Scheme model was built by adding either culvert or viaduct structures to the baseline model at the watercourse crossings.

1.3.22 Viaduct structures have been modelled by adding the Proposed Scheme embankments as Z-polygon or Z-Shape polygon layers with an opening at the viaduct crossing. The Z-polygon or Z-Shape polygon layers are Geographic Information System (GIS) polygons with elevations. Where piers were modelled, they were represented as Flow Constriction (FC) shape layers. The soffit levels were not added into the model. This was because the 1 in 1000 (0.1%) annual probability modelled peak flood levels, along with sufficient clearance, will form the basis of designing the soffit heights (refer to 'Section 3 – Design Criteria' of the Flood Risk Assessment WR-003-018).

1.3.23 Culvert structures have been modelled by adding a one dimensional network layer representing the extent of the culvert, the length of which was determined by the width of the route at the crossing point (including embankment earthworks and any landscaping). Inverts were defined at the inflow and outflow points of the culvert extracted from the LiDAR DTM for the area. This one dimensional network layer was connected to the two dimensional domain with a SXZ point link; a GIS point used in the modelling software for one dimension two dimension linking. An embankment was modelled across the route as a Z-polygon layer, covering the extent of the upstream floodplain at the route crossing so that all flow was routed through the culvert.

One dimension -two dimension linked modelling

1.3.24 In certain cases where existing one dimensional models were not representing complex channel-floodplain interactions accurately, dynamically linked one dimensional-two dimensional models were constructed. The channel component was represented in one dimension and the floodplain component in two dimensions. One dimensional-two dimensional models were built using ISIS-TUFLOW.

[6] BMT WBM (2010) *TUFLOW User Manual*.

1.3.25 The flows between the one dimensional and two dimensional model components were controlled via a GIS polyline layer (HX layer), the spill levels of which are defined by the channel bank levels or DTM levels.

1.3.26 In the Proposed Scheme scenarios, the viaduct structures are represented as discussed earlier in the two dimensional modelling section (Section 1.3.22 of this report).

Sensitivity assessments

1.3.27 Sensitivity assessments have been undertaken on various parameters of the models to reflect the uncertainties and impacts on modelled flood levels. Assessments have been carried out on inflows and culvert blockages. In the case of viaduct crossings, sensitivity was undertaken on inflows.

1.3.28 Sensitivity on inflows was carried out by varying the 1 in 100 (1%) annual probability with an allowance for climate change and the 1 in 1000 (0.1%) annual probability flows by 20%. This was undertaken for the baseline and Proposed Scheme scenarios, unless stated otherwise.

1.3.29 Sensitivity has also been carried out on Proposed Scheme scenarios with culvert structures by adding 10% blockage. Resulting models have been run for the 1 in 100 (1%) annual probability with an allowance for climate change and the 1 in 1000 (0.1%) annual probability events.

1.4 Assumptions and limitations

Hydrology

1.4.1 The catchment boundaries as taken from the FEH CD-ROM are correct and accurately represent the catchments in reality.

1.4.2 For catchments not classed as highly permeable, the ReFH method results in the most accurate estimation of flow at the location of the crossings in comparison to other methods.

1.4.3 The FEH Statistical method with permeable adjustment results in the most accurate estimation of flow at catchments classed as highly permeable.

1.4.4 The area scaling method, which is based on area, results in conservative flow estimates for catchments which are not represented in the FEH CD-ROM (refer to Section 1.2 of this report for detail).

1.4.5 There are no external influences on flow at the location of the crossing, such as significant abstractions or discharges.

1.4.6 A 20% allowance for climate change on peak flow rates has been used for the assessment of river flood risk.

Hydraulic modelling

1.4.7 Only river flood risk was considered during the hydraulic modelling in this assessment.

1.4.8 For watercourses without existing hydraulic models, the watercourse geometry was extracted from the LiDAR DTM with the channel width defined by the 5m cell

resolution of the two dimensional model. Therefore, the watercourse geometry is not well defined, the consequence of which is an underestimate of the channel conveyance and hence, an overestimation of the floodplain inundation.

1.4.9 There were certain watercourses with road crossing structures upstream or downstream of a route crossing, causing a significant impact on hydraulics. OS Mapping and aerial photography were used to assess the location of the structures. The inverts of any culvert structure were assumed to be the channel bed levels from the LiDAR DTM; and structure widths as the width of the channel.

1.4.10 In the Proposed Scheme for models involving viaducts, the structure was represented by the piers and embankments. The scheme drawings were used to obtain the footprint of the piers and the dimensions incorporated into the model. The soffits of the viaducts were not modelled as the design approach for the structures is to include a suitable clearance between peak flood level and the structure soffit.

2 Modelling at watercourse crossings

2.1 Overview

2.1.1 River modelling undertaken at the various watercourse crossings for CFA18 is summarised in Table 1, along with the modelling methodologies adopted. Figure 1 identifies the location of each of these structures.

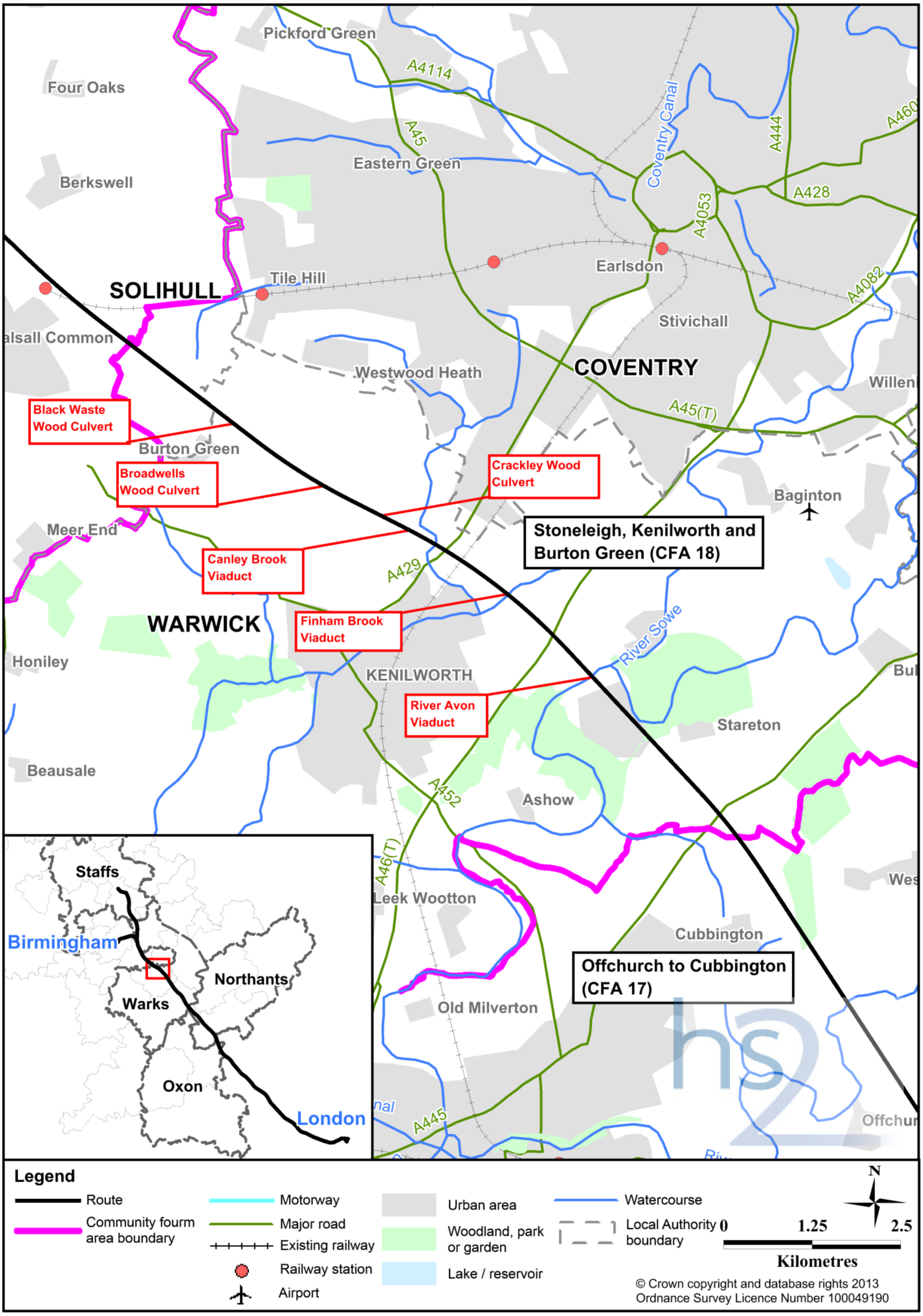
Table 1: River models at watercourse crossings

Crossing name	Watercourse identifier and map reference	Watercourse	Hydrology	Hydraulic modelling
River Avon viaduct	SWC-CFA18-001 Volume 5: Map WR-05-048, I6	Main river (River Avon)	FEH Statistical	one dimensional-two dimensional hydrodynamic
Finham Brook viaduct	SWC-CFA18-002 Volume 5: Map WR-05-048	Main river (Finham Brook)	FEH Statistical	one dimensional-two dimensional hydrodynamic
Canley Brook viaduct	SWC-CFA18-003 Volume 5: Map WR-05-049	Main river (Canley Brook)	FEH Statistical	one dimensional-two dimensional hydrodynamic
Crackley Wood culvert	SWC-CFA18-004 Volume 5: Map WR-05-049	Ordinary watercourse (tributary of Canley Brook)	ReFH	one dimensional steady state
Broadwells Wood culvert	SWC-CFA18-006 Volume 5: Map WR-05-049, D7	Ordinary watercourse (tributary of Canley Brook)	ReFH	one dimensional steady state
Black Waste Wood culvert	SWC-CFA18-007 Volume 5: Map WR-05-050, I6	Ordinary watercourse (tributary of Canley Brook)	ReFH	one dimensional steady state

2.1.2 A summary of the modelling for the culvert structures is described in Section 2.2 of this report. The details of the modelling assessment for River Avon viaduct, Finham Brook viaduct and Canley Brook viaduct are provided in Sections 2.3, 2.4 and 2.5 of this report.

2.1.3 The details of the specific modelling methodologies, hydraulic constraints and any assumptions on each of the watercourse crossings are discussed in the following sections.

Figure 1: Location plan



2.2 Culverts

2.2.1 The one dimensional ISIS hydraulic models built for the baseline and Proposed Scheme scenarios used the general methodologies for one dimensional modelling as discussed in Section 1.3.7 of this report. The structures adopted at the Crackley Brook culvert (SWC-CFA18-004), Broadwells Wood culvert (SWC-CFA18-006) and Black Waste Wood culvert (SWC-CFA18-007) along with their impacts on peak flood levels is summarised in Table 2. The structure dimensions of width (W), height (H) and length (L) in metres is also provided in this table.

2.2.2 The methodology applied for the hydrological assessment is provided in the FEH proforma in Section 0 of this report.

Table 2: Modelled peak levels for culvert crossings

Watercourse identifier	Structure dimensions (WxHxL)	Flood event	Peak flood level		Change in flood level	Length of impact upstream reach[7]
			Baseline	Scheme		
SWC-CFA18-004	2m x 1.5m x 35m	1 in 20 (5%)	76.642mAOD	76.629mAOD	-13mm	13m
		1 in 100 (1%) climate change	76.720mAOD	76.741mAOD	21mm	
		0.1%	76.793mAOD	76.872mAOD	79mm	
SWC-CFA18-006	2m x 1.5m x 70m	1 in 20 (5%)	90.813mAOD	90.859mAOD	46mm	6m
		1 in 100 (1%) climate change	90.855mAOD	90.936mAOD	81mm	
		1 in 1000 (0.1%)	90.879mAOD	91.018mAOD	139mm	
SWC-CFA18-007	2m x 1.5m x 40m	1 in 20 (5%)	112.514mAOD	112.499mAOD	-15mm	0m
		1 in 100 (1%) climate change	112.567mAOD	112.558mAOD	-9mm	
		1 in 1000 (0.1%)	112.617mAOD	112.622mAOD	5mm	

2.2.3 At the Crackley Wood culvert, peak levels for the 1 in 100 (1%) annual probability with an allowance for climate change event increase by 21mm local to the structure. The increase in peak levels of greater than 10mm is limited to 13m upstream of the crossing. Therefore, this structure will not increase flood risk.

2.2.4 At the Broadwells Wood culvert, peak levels for the 1 in 100 (1%) annual probability with an allowance for climate change event increase by 81mm. This increase is localised to the structure. The increase in peak levels of greater than 10mm is limited to 6m upstream of the crossing. Therefore, this structure will not increase flood risk.

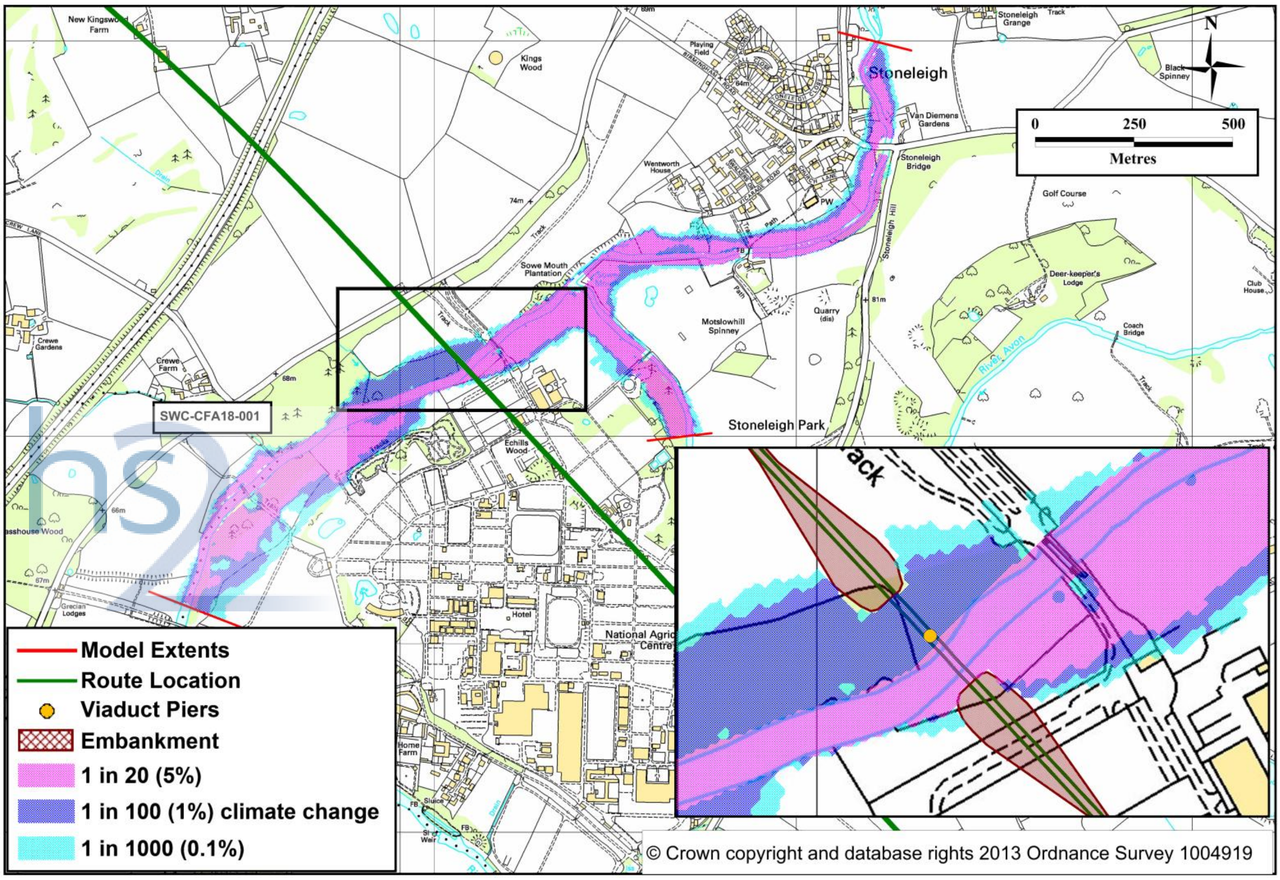
2.2.5 At the Black Waste Wood culvert peak levels for the 1 in 100 (1%) annual probability with an allowance for climate change event show no increase and hence the structure will not increase flood risk.

[7] Length of reach upstream of the scheme along which flood levels during the 1 in 100 (1%) annual probability with an allowance for climate change are greater than 10mm.

2.3 River Avon viaduct

2.3.1 This crossing consists of a viaduct structure of 74m width which will cross the River Avon SWC-CFA18-001 (Volume 5: Map Book – Water Resources, Map WR-05-048, I6) as shown in Figure 2. The watercourse flows from north-east of the crossing and continues south-west within the model extents as shown in Figure 2. The River Sowe joins with the River Avon as its tributary upstream of the crossing.

Figure 2: Crossing location plan and flood extents for River Avon viaduct



Hydrology

2.3.2 The inflows used in the hydraulic model have been derived as part of the River Avon Flood Risk Mapping Study[8]. The FEH statistical method has been used for peak flow estimation. The median annual flood (QMED) has been estimated from annual maxima (AMAX) data from the HiFlows-UK website. The shapes of the hydrographs have been based on gauged records for five events at Stareton and Stoneleigh. Further details on the hydrological calculations are provided in the River Avon Flood Risk Mapping Study[8] and not reproduced here. Table 3 provides a summary of the peak flows determined from the hydrological calculations.

[8] Environment Agency (2010) *River Avon Flood Risk Mapping Study*. Completed by Halcrow and JBA Consulting on behalf of the Environment Agency.

Table 3: Hydrology results: Model inflows for River Avon viaduct

Watercourse identifier	Environment Agency Flood Zone	1 in 20 (5%) flow	1 in 100 (1%) climate change flow	1 in 1000 (0.1%) flow	Modelled structure
SWC-CFA18-001	3	87.87m^3/s	141.94m^3/s	220.57m^3/s	Viaduct

Hydraulics

2.3.3 An ISIS-TUFLOW (one dimensional-two dimensional) model constructed as part of the River Avon Flood Risk Mapping Study has been used to inform this study. The one dimensional ISIS component of the model was originally constructed in 1995 and was calibrated in 2001. In the Flood Risk Mapping Study[8], the model was calibrated for the April 1998, December 2000, June 2007 and July 2007 events. The report states that the model is based on topographic survey data. At the location of the crossing, the original model was built in one dimensional only, using extended cross-sections to represent floodplains.

2.3.4 As part of this current study, the existing one dimensional ISIS model was truncated to a 7km stretch of the River Avon around the crossing. The existing model also included a 1.3km stretch of the River Sowe, which was part of the original model. This truncation was carried out to reduce the size of the model making it more manageable to undertake additional simulations of the crossing. A two dimensional TUFLOW domain was constructed with a 6m cell resolution to more accurately model flood depths in the floodplain. The chosen cell resolution is sufficiently small to reproduce the hydraulic behaviour of the study area which is rural around the proposed crossing.

2.3.5 A Manning's n value of 0.05 has been used to define the floodplain. The roughness value of the watercourses has been retained from the original hydraulic model. A value of 0.035 has been used. These values have been selected based on a desk-based study.

2.3.6 An ISIS normal depth boundary has been used as the downstream condition. The boundary has been generated by ISIS based on the gradient of the watercourse.

2.3.7 The Proposed Scheme model included the embankment, assuming the soffit of the viaduct is sufficiently high so as to not impact on the results. The embankment was represented as Z-shape polygon layers. Piers were not included in this model.

2.3.8 Hydraulic constraints:

- A footbridge is located approximately 100m upstream of the crossing. The constriction caused by this structure may impact on peak water levels at the crossing. The footbridge has not been included in the existing hydraulic model of the River Avon. No explanation has been found within the River Avon Flood Risk Mapping Study report[8] justifying the exclusion of this structure.

Table 4: Modelled peak levels for River Avon viaduct

Flood event	Peak flood level		Change in flood level
	Baseline	Scheme	
1 in 20 (5%)	55.326mAOD	55.323mAOD	-3mm
1 in 100 (1%) climate change	55.861mAOD	55.882mAOD	21mm
1 in 1000 (0.1%)	56.429mAOD	56.495mAOD	66mm

Figure 3: Cross-section and flood levels for River Avon viaduct

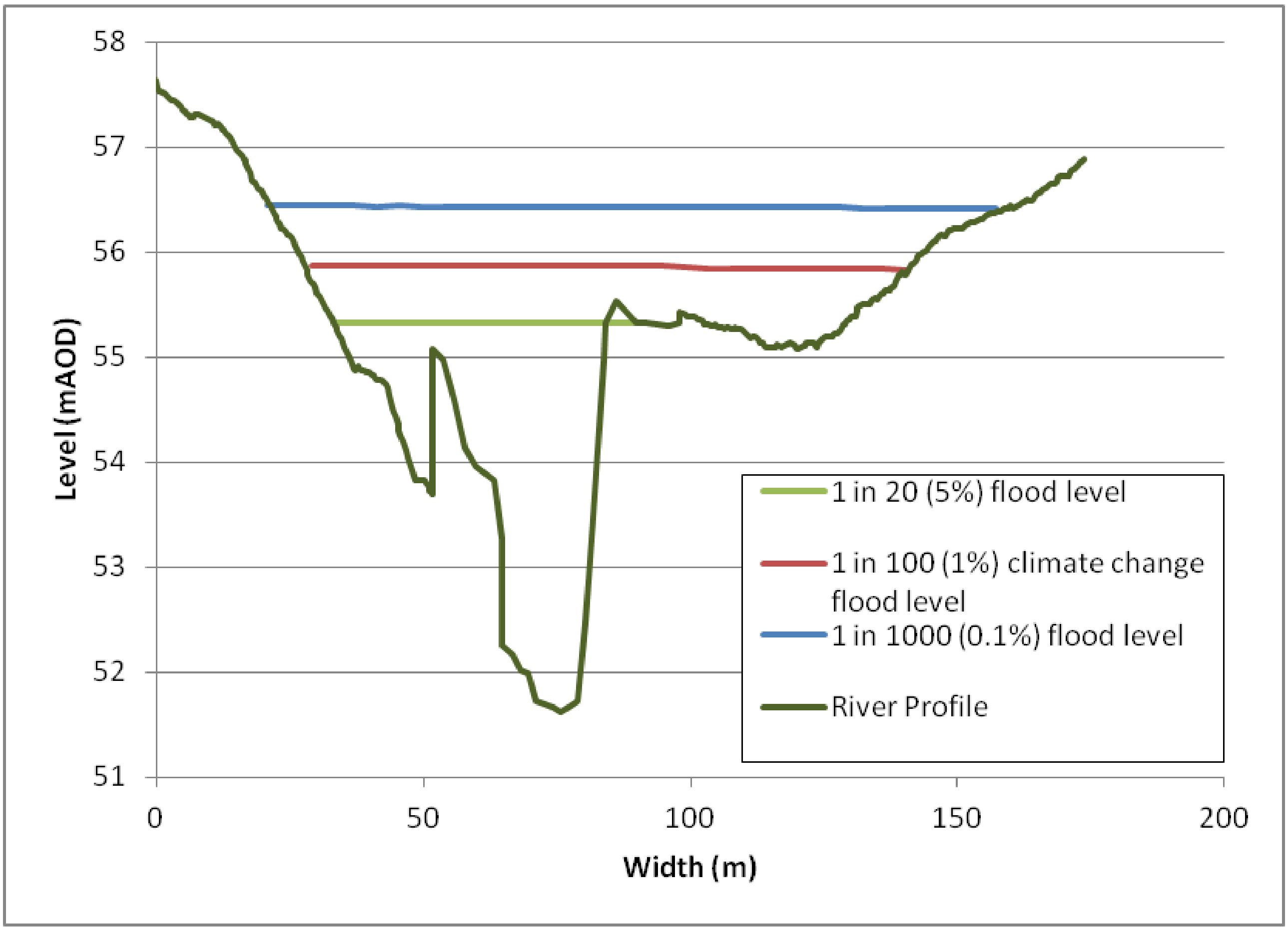
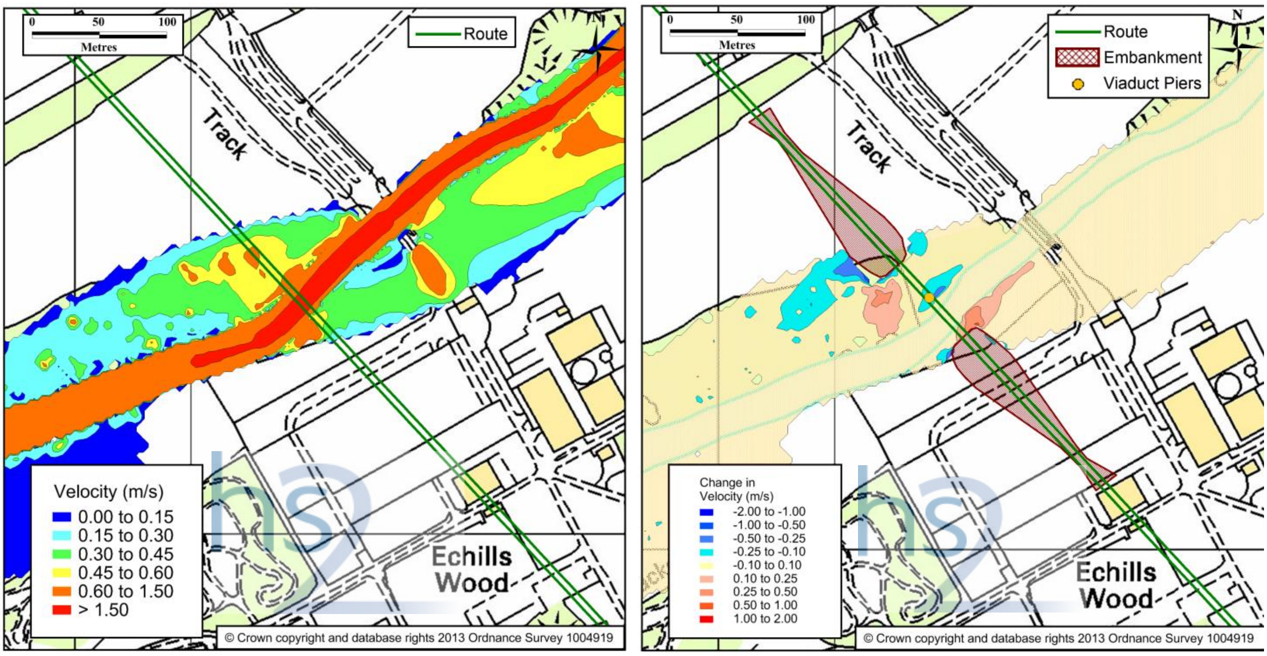


Figure 4: Modelled 1 in 100 (1%) climate change peak velocity contours for River Avon viaduct



Sensitivity assessment

2.3.9 Sensitivity assessment was carried out on the inflows for the 1 in 100 (1%) annual probability with an allowance for climate change event in the baseline model. A 20% increase of inflows caused up to a 210mm increase in channel and floodplain peak levels. The peak level including this sensitivity allowance and any scheme impacts is still well below the soffit level with at least a 600mm clearance. A 20% decrease of inflows caused up to a 240mm decrease in channel and floodplain peak levels.

2.3.10 These increases in peak levels showed overall increases in flood extents by 8% but no additional receptors have been affected.

2.3.11 Therefore, the impact of the Proposed Scheme on flood risk will still be valid with these sensitivity changes.

Conclusions

2.3.12 The Proposed Scheme showed up to a 21mm increase in peak levels for the 1 in 100 (1%) annual probability with an allowance for climate change event. The increase in peak levels of greater than 10mm was limited to a 1,077m reach upstream of the crossing. However, the flood extent changed by less than 5% which was considered minimal and did not affect any additional receptors near Stoneleigh. There were localised increases of peak velocities up to 0.55m/s at the crossing and minimal changes elsewhere.

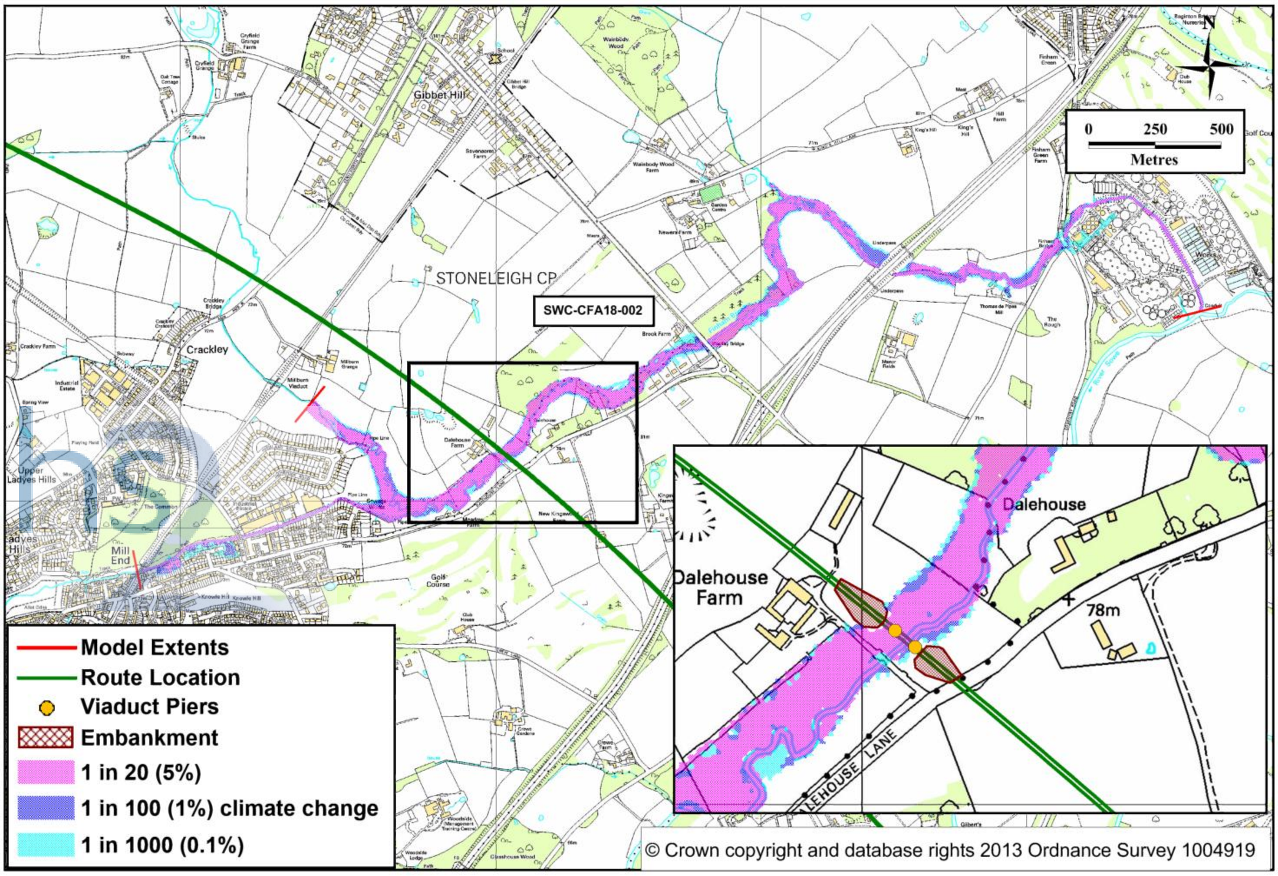
2.3.13 This impact on flood risk would be reduced through the incorporation of replacement floodplain storage, which is proposed upstream of the viaduct.

2.4 Finham Brook viaduct

2.4.1 This crossing consists of a viaduct structure of about 50m width which will cross the Finham Brook SWC-CFA18-002 (Volume 5: Map Book – Water resources, Map WR-05-

048, E6) as shown in Figure 5. The watercourse flows from south-west of the crossing and continues north-east within the model extents as shown in Figure 5.

Figure 5: Crossing location plan and flood extents for Finham Brook viaduct



Hydrology

2.4.2 The inflows used in the hydraulic model have been derived as part of the Kenilworth Hazard Mapping Study[9]. The FEH statistical method has been used for peak flow estimation. QMED has been adjusted by the Sowe at Stoneleigh gauge. A storm duration of 9.9 hours has been applied. Further details on the hydrological calculations are provided in the Kenilworth Hazard Mapping Study[9], and not reproduced here. Table 5 provides a summary of the peak flows determined from the hydrological calculations.

Table 5: Hydrology results: Model inflows for Finham Brook viaduct

Watercourse identifier	Environment Agency flood zone	1 in 20 (5%) flow	1 in 100 (1%) climate change flow	1 in 1000 (0.1%) flow	Modelled structure
SWC-CFA18-002	3	$11.41m^3/s$	$15.53m^3/s$	$22.81m^3/s$	Viaduct

Hydraulics

2.4.3 An ISIS-TUFLOW (one dimensional-two dimensional) model constructed as part of the Kenilworth Hazard Mapping Study[9] has been used to inform this study. The

[9] Environment Agency (2011) *Kenilworth Hazard Mapping Study*. Completed by JBA Consulting on behalf of the Environment Agency.

existing hydraulic model has been truncated to cover the area of interest and rerun with the current version of Tuflow (2012). Cross-sections have been added immediately upstream and downstream of the proposed crossing, by taking a copy of the nearest cross-section in the existing model (ISIS model node 'FB4547D'). The report states that cross-sectional data of Finham Brook has been based on topographical survey carried out in 2006. The topographic data used in the two dimensional domain is based on 1m LiDAR data. The model cell size is 5m. At the location of the crossing, a Manning's n value of 0.06 has been used to define the floodplain and a value of 0.042 has been used to define the watercourse, these values are taken from 'Open-channel hydraulics'[10] These existing values have been retained for the current study. Although the model was not calibrated as part of the Kenilworth Hazard Mapping Study, sensitivity testing was carried out and the model results were not overly sensitive to changes in parameters including roughness, flow, downstream boundary condition and structure blockage.

2.4.4 The Proposed Scheme model included the route embankment, assuming the soffit of the viaduct is sufficiently high so as to not impact on the results. The embankment was represented as Z-shape polygon layers. Piers were not included in this model.

2.4.5 Peak levels were extracted 20m upstream of the crossing.

2.4.6 Hydraulic constraints:

- The Dalehouse access bridge is located approximately 20m upstream of the crossing. The constriction caused by this structure may impact on peak water levels at the crossing. The bridge has been included in the hydraulic model as an ISIS arch bridge unit. Overtopping of the structure has not been included in the one dimensional model, as the 1 in 1000 (0.1%) annual probability flood levels do not reach the structure soffit level. Instead, flood water comes out of bank upstream and bypasses the structure, which is modelled in two dimensional.

Table 6: Modelled peak levels for Finham Brook viaduct

Flood event	**Peak flood level**		**Change in flood level**
	Baseline	**Scheme**	
1 in 20 (5%)	66.043mAOD	66.045mAOD	2mm
1 in 100 (1%) climate change	66.186mAOD	66.201mAOD	15mm
1 in 1000 (0.1%)	66.356mAOD	66.380mAOD	24mm

[10] Chow, V.T. (1959), *Open-Channel Hydraulics*, McGraw-Hill

Figure 6: Cross-section and flood levels for Finham Brook viaduct

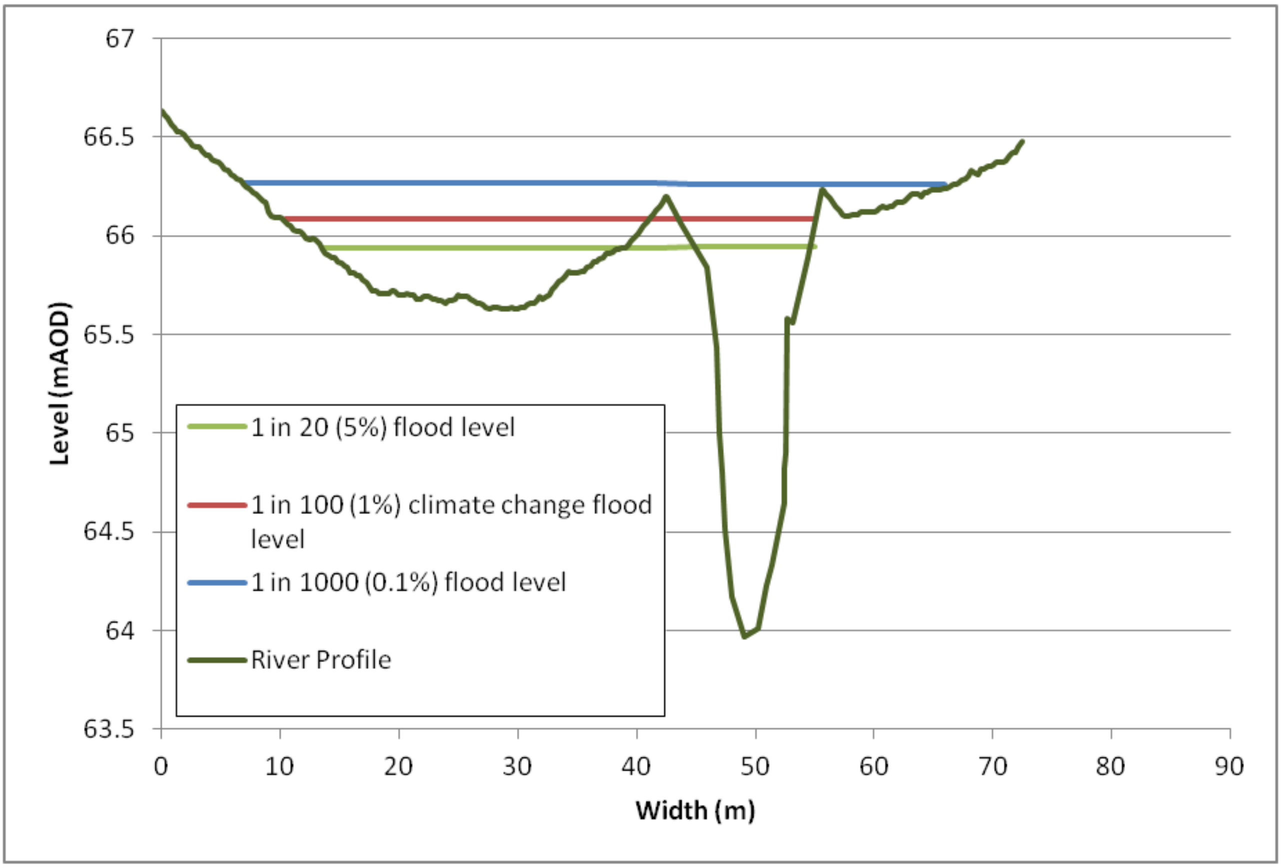
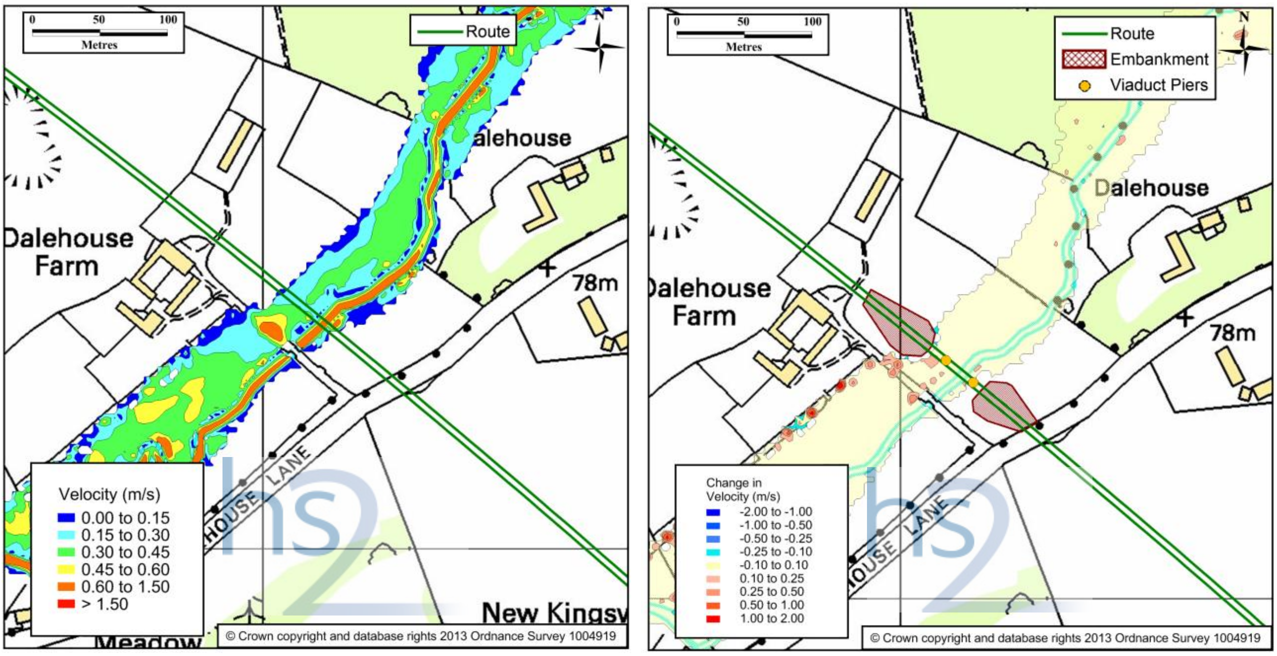


Figure 7: Modelled 1in 100 (1%) climate change peak velocity contours and scheme impacts for Finham Brook viaduct



Sensitivity assessment

2.4.7 Sensitivity assessment was carried out on the inflows for the 1 in 100 (1%) annual probability with an allowance for climate change event in the baseline model. A 20% increase of inflows showed increases of up to 80mm in channel peak levels and

110mm increase in floodplain peak levels. The peak level including this sensitivity allowance is still well below the soffit level with at least a 600mm clearance. A 20% decrease on inflow showed up to 90mm decrease in channel and floodplain peak levels.

2.4.8 There is an overall increase in flood extents of 7% due to the variation of inflows but no additional receptors have been affected apart from agricultural land.

2.4.9 Therefore, the impact of the scheme on flood risk will still be valid with these sensitivity changes.

Conclusions

2.4.10 The Proposed Scheme showed up to a 15mm increase in peak levels for the 1 in 100 (1%) annual probability with an allowance for climate change event. The increase in peak level of greater than 10mm was limited to a reach 21m upstream of the crossing. Therefore, there is minor impact on flood risk.

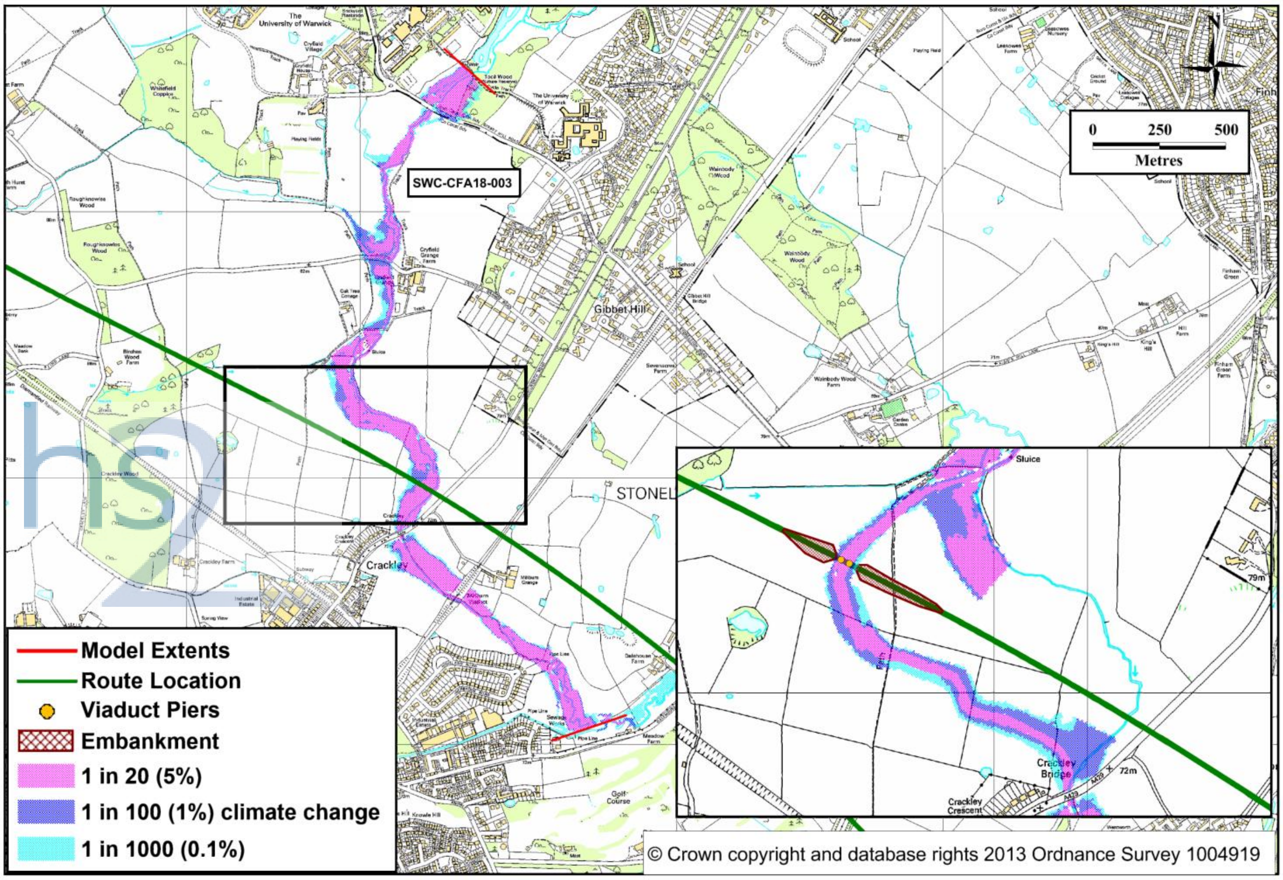
2.4.11 Although a minor impact is expected, a replacement floodplain storage area has been identified which will be incorporated if necessary.

2.4.12 There are localised increases of peak velocities of up to 0.4m/s near Dalehouse access bridge upstream and minimal changes elsewhere.

2.5 Canley Brook viaduct

2.5.1 This crossing consists of a viaduct structure of about 50m width which will cross the Canley Brook SWC-CFA18-003 (Volume 5: Map Book – Water resources, Map WR-05-049, H6) as shown in Figure 8. The watercourse flows from north of the crossing and continues south within the model extents as shown in Figure 8. The inset figure shows the schematic and flood extents of the Proposed Scheme which also includes the watercourse diversion. The watercourse is diverted to cross the route further north-west with the short reach of the original watercourse route near the crossing to be retained.

Figure 8: Crossing location plan and flood extents of Canley Brook viaduct



Hydrology

2.5.2 The inflows used in the hydraulic model have been derived as part of the Hazard Mapping Study for Coventry[11]. The flood frequency curve was derived using the FEH Statistical Method. QMED was estimated from catchment descriptors as no suitable donor catchments were found. Calibration was not undertaken on the existing model, which reduces confidence in the hydrological model. The report states that the results of the hydrological analysis were found to be consistent with historic flood records and previous studies. Further details on the hydrological calculations are provided in the Hazard Mapping Study for Coventry[11], and not reproduced here.

Table 7: Modelling inflow for Canley Brook

Watercourse identifier	Environment Agency flood zone	1 in 20 (5%) flow	1 in 100 (1%) climate change flow	1 in 1000 (0.1%) flow	Modelled structure
SWC-CFA18-003	3	8.31m^3/s	13.88m^3/s	20.77m^3/s	Viaduct

Hydraulics

2.5.3 An ISIS-TUFLOW (one dimensional/two dimensional) model constructed as part of the Hazard Mapping Study for Coventry[11] has been used to inform this study. The one dimensional ISIS component of the model is an updated version of an ISIS only model constructed in 2001 for a Strategic Flood Risk Management study. The model was

[11] Halcrow on behalf of the Environment Agency. (June 2011). *Coventry Hazard Mapping SFRM2 – Final Project Report*.

then updated in 2009 as part of a Flood Risk Assessment, and then again in 2011 for the Hazard Mapping Study for Coventry. The report accompanying the model states that the topography of the watercourse is based on survey data collected in 1999. In some cases, the cross-sections were extended using LIDAR data. The topography of the floodplain is based on 2m resolution LiDAR flown in 2005. A Manning's n value of 0.05 and 0.045 has been used to define the floodplain and watercourse, respectively; these are taken from 'Open-channel hydraulics'[12]. These values have been retained for the current study. The existing hydraulic model has been truncated to cover the area of interest and rerun with the current version of Tuflow (2012).

2.5.4 The route around Crackley passes over the Canley Brook and beneath the nearby Coventry to Leamington Spa railway line. Due to the close proximity of the watercourse and railway crossings the vertical alignment of the route is not viable. Therefore, it was proposed that the Canley Brook is realigned to the north-west.

2.5.5 In the Proposed Scheme model the realigned watercourse has the same cross-section channel geometry as the previous watercourse and the stream length is slightly longer than the existing watercourse (approximately 10% longer). The ground topography has been altered to include a new cutting for the realigned Canley Brook and the route. A new floodplain has been created for storing water and to accommodate a natural planform geometry. Whereas the existing channel was aligned with the edge of the floodplain, the realigned channel is located in the centre of the floodplain to encourage meandering. Consequently the existing bank levels have been modified to tie in with the new floodplain elevation.

2.5.6 The Proposed Scheme contains a bund part way along the previous river alignment and the storage capacity of the area downstream of the embankment is reduced by 50%. The Proposed Scheme model included the embankment, assuming the soffit of the viaduct is sufficiently high so as to not impact on the results. The embankment was represented as Z-shape polygon layers. Piers were not included in this model.

2.5.7 Since the realigned watercourse crosses the route at a different location to the original alignment, it was necessary to extract peak levels 258m upstream of the crossing. This ensures comparison of peak levels between the baseline and Proposed Scheme models at the same location. Another point further upstream near Cryfield Grange Road was taken to extract peak levels, in order to assess the scheme impacts on flood risk near vulnerable properties.

2.5.8 Hydraulic constraints:

- Crackley Bridge is located approximately 190m downstream of the proposed crossing. The constriction caused by this structure may impact on peak water levels at the crossing. Kenilworth Road is raised as it passes over the Canley Brook and acts as an embankment, retaining out of bank flood waters behind it. The structure has been included in the hydraulic model and represented using an ISIS arch bridge unit. Overtopping of the structure is modelled in two dimensional. The model results show overtopping is not predicted to occur for all flood events up to and including the 1 in 1000 (0.1%) annual probability

[12] Chow, V.T. (1959), *Open-Channel Hydraulics*, McGraw-Hill

event;

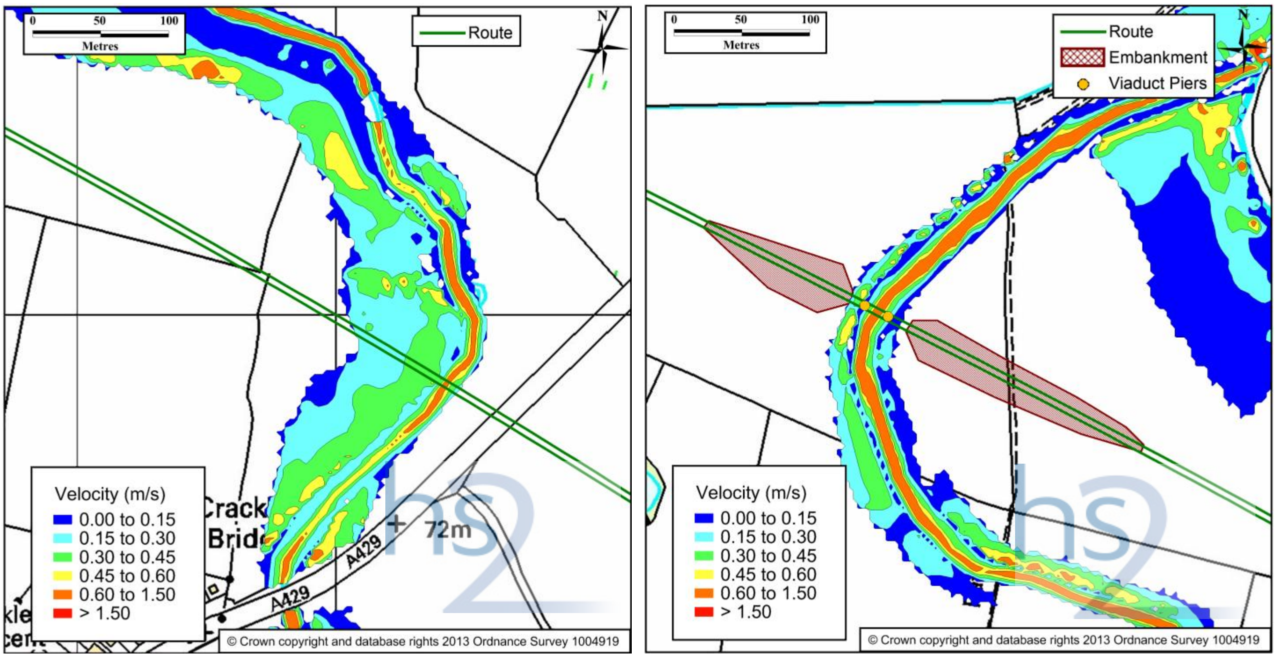
- Millburn Viaduct is located approximately 500m downstream of the proposed crossing. The structure has not been included in the existing model of the Canley Brook. Aerial photos of the structure show that the size of the structure is sufficiently large and unlikely to impact on water levels around the crossing. The embankment has been represented with elevations taken from the LiDAR DTM; and
- A sluice is located downstream of Cryfield Grange Farm. The structure was not included in the existing model of the Canley Brook.

Table 8: Modelled flood levels for Canley Brook viaduct

Flood event	Peak flood level		Change in flood level
	Baseline	Scheme	
1 in 20 (5%)	71.498mAOD	71.639mAOD	141mm
1 in 100+CC (1%+CC)	71.601mAOD	71.734mAOD	133mm
1 in 1000 (0.1%)	71.694mAOD	71.833mAOD	139mm

Figure 9: Cross-section and flood levels for Canley Brook viaduct

Figure 10: Peak velocity contour of 1 in 100 (1%) climate change event for Canley Brook viaduct



Baseline

Proposed Scheme

Sensitivity assessment

2.5.9 Sensitivity assessment was carried out on inflows for the 1 in 100 (1%) annual probability with an allowance for climate change event on the baseline model. A 20% increase on inflows causes an increase of peak levels of 120mm on the channel and 80mm on the floodplain. The peak level including this sensitivity allowance and any impacts due to the scheme is still well below the soffit level with at least a 600mm clearance. A 20% decrease on inflows causes a decrease of peak level of 110mm on the channel and 50mm on the floodplain.

Conclusions

2.5.10 The Proposed Scheme model showed up to 133mm increase in peak levels for the 1 in 100 (1%) annual probability with an allowance for climate change event. The increase in peak levels greater than 10mm is limited to 400m upstream of the crossing, affecting mostly agricultural land.

2.5.11 Near Cryfield Grange Road, the model showed a 1mm increase in peak levels for the 1 in 100 (1%) annual probability with an allowance for climate change event. Therefore, the Proposed Scheme has negligible impact on flood risk near the vulnerable receptors at this location.

2.5.12 The final detailed design of this crossing is yet to be confirmed however, a short reach of the original watercourse was identified as an area for flood storage which would reduce the impact on flood risk.

3 FEH proformas

3.1 Overview

3.1.1 This section provides the FEH Proformas for the hydrological calculations of the watercourses for which there were no existing hydrology available.

3.1.2 The FEH Proformas are based on the Environment Agency supporting document to the flood estimation guidelines[13].

3.1.3 The FEH Proformas provided here cover the watercourse at crossings Crackley Wood culvert, Broadwells Wood culvert and Black Waste Wood culvert.

3.1.4 Following review, flows for a further three crossings, which are main rivers (River Avon viaduct, Finham Brook viaduct and Canley Brook viaduct) have been adopted from the following existing detailed mapping studies:

- Hazard Mapping Study for Coventry[8];
- Kenilworth Hazard Mapping Study[9]; and
- River Avon Flood Risk Mapping Study[5].

3.1.5 The Flood Estimation Calculation Records for these studies are available with the above mentioned reports and have not been reproduced here.

3.2 Crackley Wood culvert, Broadwells Wood culvert and Black Waste Wood culvert

Method statement

Overview of requirements for flood estimates

Item	Comments
Give an overview which includes: Purpose of study Approx. no. of flood estimates required Peak flows or hydrographs? Range of return periods and locations Approx. time available	This proforma outlines the hydrological calculations carried out for the assessment of flood risk for the Proposed Scheme. As part of the Proposed Scheme, structures may need to be incorporated into the design where a number of watercourses pass beneath the route. The capacity of these structures needs to be determined to ensure there is no increase to flood risk. It is vital at this stage that the proposed structures are not under designed and hence conservative flows are necessary in line with current requirements of the Proposed Scheme. At a later stage, if a more in-depth assessment determines lower flows, and hence smaller structures would have sufficient capacity, this is acceptable. Country North is a 75km section of the route from north of Lichfield to Banbury. Flows are required where the rail line crosses all watercourses. This assessment outlines the derivation of flows and hydrographs at three locations for the 1 in 20 (5%) annual probability, 1 in 100 (1%) annual probability, 1 in 100 (1%) annual probability with an allowance for climate change and the 1 in 1000 (0.1%) annual probability.

[13] Environment Agency, (2012). *Flood estimation guidelines, operational instruction 197_08*.

Overview of catchment

Item	Comments
Brief description of catchment, or reference to section in accompanying report	The three crossings have separate catchments which range in size from 0.13km^2 to 0.97km^2. The level of urbanisation in the catchments ranges from rural to urbanised.

Source of flood peak data

Was the HiFlows UK dataset used? If so, which version? If not, why not? Record any changes made	Yes – Version 3.1.2, December 2011.

Gauging stations (flow or level)

3.2.1 Gauging stations at the sites of flood estimates or nearby at potential donor sites.

3.2.2 Local donor sites have been sought however in most cases the catchment area of the subject catchment was found to be significantly smaller than that of any potential local donor.

Watercourse	Station name	Gauging authority number	NFRA number (used in FEH)	Grid reference	Catchment area (km²)	Type (rated/ ultrasonic/ level …)	Start and end of flow record
Not applicable							

Data available at each flow gauging station

Station name	Start and end of data in HiFlows-UK	Update for this study?	Suitable for QMED?	Suitable for pooling?	Data quality check needed?	Other comments on station and flow data quality – e.g. information from HiFlows-UK, trends in flood peaks, outliers.
Not applicable						
Give link/reference to any further data quality checks carried out						

Rating equations

Station name	Type of rating e.g. theoretical, empirical; degree of extrapolation	Rating review needed?	Reasons – e.g. availability of recent flow gaugings, amount of scatter in the rating.
Not applicable			
Give link/reference to any rating reviews carried out			

Other data available and how it has been obtained

Type of data	Data relevant to this study?	Data available?	Source of data and licence reference if from Environment Agency	Date obtained	Details
Check flow gaugings (if planned to review ratings)	No				
Historic flood data – give link to historic review if carried out.	No				
Flow data for events	No				
Rainfall data for events	No				
Potential evaporation data	No				
Results from previous studies	No				
Other data or information (e.g. groundwater, tides)	No				

Initial choice of approach

Is FEH appropriate? (it may not be for very small, heavily urbanised or complex catchments) If not, describe other methods to be used.	Yes. There are crossings which have small catchments, which are smaller than 0.5km^2. Current guidance recommends that for catchments smaller than 0.5 km^2, run-off estimates should be derived from FEH methods applied to the nearest suitable catchment above 0.5 km^2 for which descriptors can be derived from the FEH CD-ROM and scaled down. The general approach to flow estimation for minor watercourses is: - Define catchment area either on the FEH CD-ROM or using the DTM if catchment area is less than 0.5km^2. - Check catchment descriptors and adjust where necessary. - Calculate critical duration for the catchment of each crossing using the equation, D (hrs) = Tp*(1+SAAR/1000). - Calculate flows using the ReFH method from catchment descriptors.
Outline the conceptual model, addressing questions such as: Where are the main sites of interest? What is likely to cause flooding at those locations? (peak flows, flood volumes, combinations of peaks, groundwater, snowmelt, tides …) Might those locations flood from runoff generated on part of the catchment only, e.g. downstream of a reservoir? Is there a need to consider temporary debris dams that could collapse?	The main sites of interest are at the crossing locations and hence are the points at which flow has been derived. At each point where flows have been derived has been named in accordance with the associated watercourse identifier. At this stage it is considered that peak flows are likely to be the main cause of flooding, following development, due to the potentially constricting culvert or bridge. As part of this assessment it is not currently deemed necessary to consider the risk of a temporary dam collapse; however, this may be considered in future.

Any unusual catchment features to take into account? **e.g. highly permeable – avoid ReFH if BFIHOST>0.65, consider permeable catchment adjustment for statistical method if SPRHOST<20%** **highly urbanised – avoid standard ReFH if URBEXT1990>0.125; consider FEH Statistical or other alternatives; consider method that can account for differing sewer and topographic catchments** **pumped watercourse – consider lowland catchment version of rainfall-runoff method** **major reservoir influence (FARL<0.90) – consider flood routing** **extensive floodplain storage – consider choice of method carefully**	The catchment Crackley Wood culvert has BFIHOST greater than 0.65, however SPRHOST is greater than 20%. Crackley Wood culvert is a minor crossing and given the SPRHOST is greater than 20% the ReFH method is considered suitable. All other catchments are within a suitable range of urbanisation for the ReFH method. All catchments have a FARL greater than 0.9.
Initial choice of method(s) and reasons **Will the catchment be split into sub-catchments? If so, how?**	For the purposes of this study, an assessment has been undertaken for crossings of minor watercourses in which the ReFH method from catchment descriptors was utilised.
Software to be used (with version numbers)	FEH CD-ROM v3.0[14] WINFAP-FEH v3.0[15] ReFH calculations – ReFH spreadsheet / ISIS

Summary of subject sites

Site code (taken from watercourse identifier)	**Watercourse**	**Site**	**Easting**	**Northing**	**Area on FEH CD-ROM**	**Revised area if altered**
SWC-CFA18-004	Ordinary watercourse (tributary of the Canley Brook)	Crackley Wood culvert	429200	274400	0.97km^2	Not altered.
SWC-CFA18-006	Ordinary watercourse (tributary of the Canley Brook)	Broadwells Wood culvert	427910	275130	Too small to be defined on the FEH CD-ROM. Catchment Descriptors (CDs) extracted from downstream catchment and adjusted.	0.27km^2
SWC-CFA18-007	Ordinary watercourse (tributary of the Canley Brook)	Black Waste Wood culvert	427090	275740	Too small to be defined on the FEH CD-ROM. CDs extracted from downstream catchment and adjusted.	0.13km^2
Reasons for choosing above locations	Locations the route is proposed to cross the respective watercourses.					

[14] *FEH CD-ROM v3.0* © NERC (CEH). © Crown copyright. © AA. 2009. All rights reserved.
[15] *WINFAP-FEH v3* © Wallingford HydroSolutions Limited and NERC (CEH) 2009.

Important catchment descriptors at each subject site (incorporating any changes made)

Site code	FARL	PROPWET	BFIHOST	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	SPRHOST	URBEXT 2000	FPEXT
SWC-CFA18-004	1.000	0.30	0.659	0.84	27.5	684	28.70	0.0000	0.0000
SWC-CFA18-006	1.000	0.30	0.561	0.49	31.9	687	34.18	0.0900	0.1000
SWC-CFA18-007	1.000	0.30	0.516	0.32	55.7	689	36.52	0.0800	0.0900

Checking catchment descriptors

Record how catchment boundary was checked and describe any changes (refer to maps if needed)	The boundary of each catchment has been checked against contours from OS 50K mapping and DTM where available. Adjustment to the catchment boundaries and area was made where necessary. The boundary of catchments not represented on the FEH CD-ROM was determined using the DTM. Changes to the catchment boundary and resulting area are provided in the earlier section of 'Summary of subject sites'.
Record how other catchment descriptors (especially soils) were checked and describe any changes. Include before/after table if necessary.	This proforma outlines the hydrological assessment for the initial stage of assessment. Broad scale checks of catchment descriptors have been carried out. The catchment descriptors for catchments not represented on the FEH CD-ROM were extracted for downstream or adjacent catchments. The AREA was adjusted and the DPLBAR was recalculated based on the new area (AREA^0.548). The average slope has been calculated using the Weighted Height-Distance Method. Other catchment descriptors were sensibility checked for suitability. For all catchments, where the catchment area has changed the new catchment area has been used to calculate the DPLBAR (AREA^0.548). The underlying geology and soils have been reviewed on a broad scale for the larger area of interest and the catchment values for BFIHOST and SPRHOST values appear reasonable, no changes were considered necessary at this stage.
Source of URBEXT	URBEXT1990 (ReFH method)
Method for updating of URBEXT	CPRE formula from FEH Volume 4 on URBEXT1990 / CPRE formula from 2006 CEH report on URBEXT2000.

Parameters for ReFH model

3.2.3 Note: If parameters are estimated from catchment descriptors, they are easily reproducible so it is not essential to enter them in the table.

Site code	Method: OPT: Optimisation BR: Baseflow recession fitting CD: Catchment descriptors DT: Data transfer (give details)	Tp Time to peak	Cmax Maximum storage capacity	BL (hours) Baseflow lag	BR Baseflow recharge
SWC-CFA18-004	CD	2.06 hours	536.03mm	38.25	1.55

Site code	Method: OPT: Optimisation BR: Baseflow recession fitting CD: Catchment descriptors DT: Data transfer (give details)	Tp Time to peak	Cmax Maximum storage capacity	BL (hours) Baseflow lag	BR Baseflow recharge
SWC-CFA18-006	CD	1.07 hours	460.00mm	24.41	1.30
SWC-CFA18-007	CD	0.74 hours	424.88mm	22.14	1.19
Brief description of any flood event analysis carried out (further details should be given below or in a project report)		Potential donor sites were sought for the catchments of major crossings using the FEH CD-ROM, HiFlows-UK database and from within the pooling groups. In general stations local to the catchments were either significantly larger, heavily urbanised or had very different catchment descriptors and were unsuitable donor stations.			

Design events for ReFH method

Site Code	Urban or rural	Season of design event (summer or winter)	Storm duration	Storm area for ARF (if not catchment area)
SWC-CFA18-004	Rural	Winter	3.5 hours	ReFH Design Standard
SWC-CFA18-006	Rural	Summer	1.8 hours	ReFH Design Standard
SWC-CFA18-007	Rural	Summer	1.2 hours	ReFH Design Standard
Are the storm durations likely to be changed in the next stage of the study, e.g. by optimisation within a hydraulic model?			Storm durations have not been optimised within the hydraulic model. It is unlikely that the storm durations will be altered as part of the next stage of hydraulic modelling.	

Flood estimates from the ReFH method

Site Code	Flood peak for the following annual probability event (%)			
	1 in 20 (5%)	1 in 100 (1%)	1 in 100 (1%) climate change	1 in 1000 (0.1%)
SWC-CFA18-004	0.34m^3/s	0.50m^3/s	0.60m^3/s	0.96m^3/s
SWC-CFA18-006	0.20m^3/s	0.29m^3/s	0.35m^3/s	0.55m^3/s
SWC-CFA18-007	0.13m^3/s	0.19m^3/s	0.23m^3/s	0.36m^3/s

Discussion and summary of results

Comparison of results from different methods

3.2.4 This table compares peak flows from various methods with those from the FEH Statistical method for two key return periods. Blank cells indicate that results for a particular site were not calculated using that method.

Site Code	Peak Flows			
	1 in 20 (5%)		1 in 100 (1%)	
	ReFH	FEH Statistical PG	ReFH	FEH Statistical PG
SWC-CFA18-004	0.34m^3/s		0.50m^3/s	
SWC-CFA18-006	0.20m^3/s		0.29m^3/s	
SWC-CFA18-007	0.13m^3/s		0.19m^3/s	

Final choice of method

Choice of method and reasons – include reference to type of study, nature of catchment and type of data available.	Flow estimates calculated using the ReFH method from catchment descriptors extracted from the FEH CD-ROM and adjusted where necessary (i.e. for small catchments less than 0.5km^2, or where incorrect) have been provided for the three crossings and are considered appropriate for the requirements of the study. It is vital at this stage that the proposed structures are not under designed and hence conservative flows are necessary in line with current requirements of the Proposed Scheme. Therefore, peak flows from the ReFH method have been used in the hydraulic modelling for these three crossings.

Assumptions, limitations and uncertainty

List the main assumptions made (specific to this study)	For the two catchments which were too small to be defined on the FEH CD-ROM, it has been considered appropriate to extract catchment descriptors from the FEH CD-ROM from catchments slightly further downstream or from an adjacent catchment. Catchment descriptors including AREA, DPLBAR, URBEXT, DPSBAR were adjusted to reflect the smaller catchment as required. Refer to sections 'Summary of subject sites' and 'Important catchment descriptors at each subject site'.
Discuss any particular limitations, e.g. applying methods outside the range of catchment types or return periods for which they were developed	At this stage of the study requires conservative flow estimates for design purposes and therefore the ReFH method peak flow estimate has been used for this catchment.
Give what information you can on uncertainty in the results – e.g. confidence limits for the QMED estimates using FEH 3 12.5 or the factorial standard error from Science Report SC050050 (2008).	There is some uncertainty with the results; however, it is considered that the results are conservative and hence would be overestimating, rather than underestimating.
Comment on the suitability of the results for future studies, e.g. at nearby locations or for different purposes.	Peak flow estimates have been produced for the purposes of this assessment and should not be used outside of this study except for comparative purposes.
Give any other comments on the study, for example suggestions for additional work.	When the assessment moves to the detailed design phase the FEH Statistical method should be carried out for all suitable catchments for comparative purposes and to provide a greater level of confidence with the results. If there is the opportunity to install temporary flow gauges at the un-gauged crossings, this may also improve confidence in design flows at the detailed design phase.

Checks

Are the results consistent, for example at confluences?	Not applicable separate catchments assessed.
What do the results imply regarding the return periods of floods during the period of record?	Not applicable
What is the 100-year growth factor? Is this realistic? (The guidance suggests a typical range of 2.1 to 4.0)	Not determined.
If 1000-year flows have been derived, what is the range of ratios for 1000-year flow over 100-year flow?	Range between 1.89 and 1.92.
What range of specific runoffs (l/s/ha) do the results equate to? Are there any inconsistencies?	Different catchments so not comparable.
How do the results compare with those of other studies? Explain any differences and conclude which results should be preferred.	None.
Are the results compatible with the longer-term flood history?	Not investigated as part of the initial assessment.
Describe any other checks on the results	None.

Final results

Site code	**Flood peak for the following flood events**			
	1 in 20 (5%)	**1 in 100 (1%)**	**1 in 100 (1%) climate change**	**1 in 1000 (0.1%)**
SWC-CFA18-004	0.34m^3/s	0.50m^3/s	0.60m^3/s	0.96m^3/s
SWC-CFA18-006	0.20m^3/s	0.29m^3/s	0.35m^3/s	0.55m^3/s
SWC-CFA18-007	0.13m^3/s	0.19m^3/s	0.23m^3/s	0.36m^3/s